An Agent-based Approach for Smart Energy Grids

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Abstract: The increasing demand for energy and the availability of several solutions of renewable energy sources has stimulated the formulation of plans aiming at expanding and upgrading existing power grids in several countries. According to NIST, smart grid will be one of the greatest achievements of the 21st century. By linking information technologies with the electric power grid to provide electricity with a brain, the smart grid promises many benefits, including increased energy efficiency, reduced carbon emissions, and improved power reliability. In this paper we present an agent based architecture for supporting collection and processing of information about local energy production and storage resources of neighborhoods of individual houses and to schedule the energy flows using negotiation protocols.

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1 INTRODUCTION

The increasing demand for energy and the availability of several solutions of renewable energy sources has stimulated the formulation of plans aiming at expanding and upgrading existing power grids in several countries. Contextually, the big improvement in ICT (Information e Communications Technology) has created a convergence of scientific and industrial interests in the exploitation of these technologies for implementing a process of structural transformation at each stage of the energy cycle. This convergence has given rise to modernized electrical grid that uses ICT to gather and act on information, such as about the behaviors of suppliers and consumers, in an automated way to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity (U.S. Office of Electricity Delivery & Energy Reliability, 2012). Smart grid will be one of the greatest achievements of the 21st century. By linking information technologies with the electric power grid to provide "electricity with a brain" the smart grid promises many benefits, including increased energy efficiency, reduced carbon emissions, and improved power reliability (NIST, 2012). The main aim here is to reduce the huge economic and environmental costs deriving from the utilization of the old paradigms. Due to ICT technologies, the electricity grid can change from a hierarchical, unidirectional and centralized grid, to a distributed and networked grid. The electricity grid gets power generated from consumers, who exploit renewable energy resources, and using ICT network as an orchestrator to manage the complexity resulting from bidirectional power flows and less predictable demand. This ambitious vision requires substantial advances in intelligent decentralized control mechanisms that increase economic efficiency, while keeping the physical properties of the network within tight permissible bounds(Miller et al., 2012). In fact this paradigm shift, from hierarchical to distributed, brings with it a number of difficulties due to the bidirectional and decentralized flow of both energy and information and to the heterogeneity and less predictable behaviour of its components. In this context CoSSMiC, an ICT European project, aims at fostering a higher rate of self-consumption of decentralised renewable energy production, using innovative autonomic systems for management and control of power micro-grids on users behalf. A relevant challenge is the development of selfish agents that, driven by the user's preferences, pursue some goals to improve the utility of their owners. The alignment of agents' selfishness with user's interest will allow to win the user's trust. On the other hand, behavior patterns, which improve also the performance of power grids, will provide the desired smartness. In this paper we present an agent based architecture for supporting agents to collect information about local energy production and storage resources of individual houses, belonging to the same neighborhood, and to schedule the energy flows using negotiation protocols. The paper is organized as

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follows: Section 2 reviews some related works; Section 3 presents an overview of CoSSMiC project; in Sections 4and 5.1 we describe the requirements of the solution and a prototype of its implementation; conclusions are drawn in Section 6.

2 RELATED WORK

The scientific community investigates different priorities in the field of smart grids. Some examples are market deregulation, ICT architecture, IT security and data protection, energy efficiency, integration of renewable energies, supply security/Grid bottlenecks/Grid expansion, decentralised energy production, smart meterology, storage devices and load flexibilisation. Much effort has been spent on the investigation in this field of agents technology(Rogers et al., 2012). In (Rodden et al., 2013) authors consider how consumers might relate to future smart energy grids, and how exploiting software agents to help users in engaging with complex energy infrastructures. In (Truong et al., 2013) authors define a methodology for predicting the usage of home appliances. An agent based prediction algorithm captures the everyday habits by exploiting their periodic features. In addition, the algorithm uses a episode generation hidden Markov model (EGH) to model the interdependency between appliances. In (Isabel Praa and Cordeiro, 2005) a Multi-Agent system architecture simulates and analyses Competitive Electricity Markets combining bilateral trading with power exchange mechanisms. Several heterogeneous and autonomous intelligent agents representing the different independent entities in Electricity Markets are used and a detailed description of a promising algorithm for Decision Support is presented and used to improve agents bidding process and counter-proposals definition. Agents are endowed with historical information about the market including past strategies of other players, and have strategic behaviour to face the market. (Jia-hai et al., 2005) presents the architecture and negotiation strategy of an agent-based negotiation platform for power generating and power consuming companies in contract electricity market. An intelligent agent implements the negotiation process by selecting a strategy using learning algorithms. Agent uses fuzzy logic modification of basic Genetic Algorithm to accomplish strategy optimization and reinforced learning algorithm to modify the parameter of negotiation tactics and strategy under different situations. Protocol Operation Semantics is used as agent communication mechanism to handle sequential message exchange. In (Telesca et al., 2007) an Open Negotiation Environment (ONE) provides sophisticated negotiation processes and supports a model of collaboration and trust based on the idea of "collaborative multi-agent systems", where agents can work and learn with other trusted agents and develop collaborative learning schemes. ONE allows an organisation to dynamically package and compose complex services by negotiating alliances. Users can define a custom negotiation process taking into account several specification such as negotiation rules, legal rules, pricing policy, etc using a XML based scripting language. The runtime negotiation engine will be in charge of executing the defined process as a facilitator between parties that take into account the defined strategy and rules until the negotiation is successfully closed. In (Capodieci et al., 2012b) and (Capodieci et al., 2012a) an agent-based approach to manage negotiation among the different parties is presented. The goal is to propose adaptive negotiation strategies for energy trading in a deregulated market. In particular, strategies derived from game theory are used, in order to optimize energy production and supply costs by means of negotiation and adaptation. To manage negotiation between agents the El Farol Bar Game is used and the equilibrium model is proposed in (Whitehead, 2008). Agents act on behalf of end users, thus implying the necessity of being aware of multiple aspects connected to the distribution of electricity. These aspects refer to outside world variables like weather, stock market trends, location of the users etc. A web service integration in which agents contracting energy will automatically retrieve data to be used in adaptive and collaborative aspects. Moreover, a MAS (Multi Agent System) is used to simulate a new paradigm for collaboration among various actors and it is used the adaptive collaboration strategies to calculate the energy that the big companies must provide. In particular, this energy is calculated by subtracting the amount of energy required and the amount of energy that the producers can supply. In (Peleg and Rosenschein, 2012) multiagent resource allocation in a competitive peer-to-peer environment is addressed making use of micro-payment techniques, along with concepts from random graph theory and game theory. It provides an analytical characterization of protocol, and specifies how an agent should choose optimal values for the protocol parameters. In (Brazier et al., 2012) authors claim that agent and peer-to-peer based decentralized self-management can change the future of energy markets in which the power grid plays a core role. Both consumers and providers of energy are autonomous systems, represented by software agents or peers capable of self-management, virtual organizations of systems can emerge and adapt when necessary. Overlay structures (as defined within p2p research) define adaptive communication structures, multi-agent research provides interaction patterns. Our contribution, and in particular the CoSSMic project, is going beyond the state of art by supporting negotiation among final users on real power grid, that to the authors' knowledge has not been implemented before.The framework that will be validated on real infrastructures by trials that involve inhabitants of three different European countries. Both software and hardware will be integrated and customized ad hoc to be compliant with existing installations. Finally we have experience in building network of agents both in smart cities applications (Amato et al., 2012a) and for negotiation and brokering of computational resources in Cloud markets(Venticinque et al., 2012; Amato et al., 2012b).

3 THE CoSSMic SCENARIO

CoSSMic (Collaborating Smart Solar-powered Micro-grids - FP7-SMARTCITIES-2013) is an ICT European project that aims at fostering a higher rate for self-consumption ($< 50\%$) of decentralised renewable energy production by innovative autonomic systems for management and control of power micro-grids on users' behalf. This will allow household and neighborhood power optimisation and sales to the network. In addition CoSSMic will provide a higher degree of predictability of power deliveries for the large power companies, and it will satisfy the requirements and achieve the benefits discussed above. CoSSMic research partners are Stiftelsen Sintef International Solar Energy Research Center Konstanz, Second University of Naples, Norges Teknisk-Naturvitenskapelige Universitet, Sunny Solartechnik, Boukje.com Consulting. City of Konstanz in Germany and province of Caserta in Italy are project partners that provide trial sites for experimental activities and validation of results. In CoSSMIc a micro-grid is typically confined in a smart home or an office building, and embeds local generation and storage of solar power, and a number of power consuming devices. In addition electric vehicles will connect and disconnect dynamically, thus representing a dynamically varying storage capacity. In Figure 1 an overview of the reference scenario is shown. On the left side, micro-grids, embedded with renewable energy production, storage capacity and consumption, are combined with an intelligent ICT platform. Such a framework will allow for both peer-to-peer collaboration between

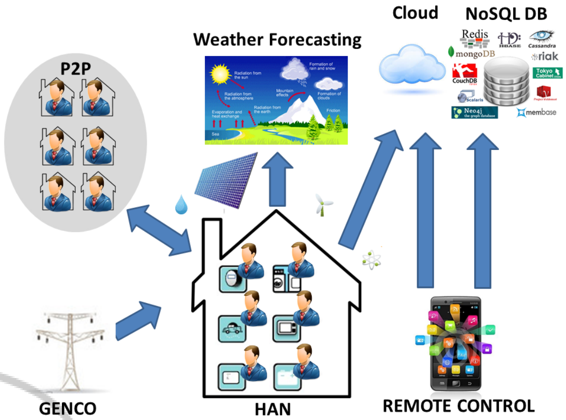

Figure 1: CoSSMIc reference scenario.

micro-grids in a neighborhood, forming a cluster. All the cluster collaborates for the reduction of variation of decentralised renewable energy transfer to the grid and a higher rate for self-consumption. At the same time the central power grid enables the provision of energy for contingent requirements or to complement the neighborhood resources. Agents are used to manage the Home Area Network (HAN) with the aim to optimize self-consumption rates using renewable energy sources. Households with renewable energy facilities can sell excess energy to the neighborhood while households that needs more energy can buy it. Ideally, the pool is at the zero level when the energy production within the household matches the consumption, and there is not external exchange of energy. This agents pool also participates to two different market places: for the energy exchange within the neighborhood, and for the exchange with the outside world. The design of an ICT architecture is necessary to support sharing of information, scheduling of exchanges between power producers and storages in accordance with policies defined by owners, collection of data from weather stations, weather forecasts, and habits and plans of participants. Cloud services will be provided to connect distributed installations, to allows for power monitoring and updating policies by users. Control agents can query the service to update their knowledge and plan new schedules by negotiating at eventually changed conditions. In the same way agents can use information retrieved by weather forecasting services to make projections about energy needs or to make market forecasts. The behaviour of the smart micro-grids will be governed business models based on credits. This should ensure rewards to the users willing to share resources and collaborate to optimise the overall working of the power grid. The design and development of such a framework should support the communication among agents over a

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peer-to-peer overlay to negotiate the scheduling of power sources to energy storages. Agents will act autonomously guided by rules and policies set by the users and agree on a coordinated behaviour towards the central power grid. The distributed agents network will also implement a distributed infrastructure for metering and monitoring the real production, consumption and energy level of those smart grids that accept to use Cloud services to provide relevant information about their status. This information will be exploited for collecting and studying experimental activities conducted at trial sites and to validate developed techniques and technologies. NoSQL data stores will be used with this purpose because they are designed to scale well horizontally and run on commodity hardware. NoSQL data stores come up with a number of key features (Cattell, 2012), such as the ability to horizontally scale simple operation throughput over many servers, the ability to replicate and to distribute (partition) data over many servers, a simple call level interface or protocol (in contrast to a SQL binding), a weaker concurrency model than the ACID transactions of most relational (SQL) database systems, efficient use of distributed indexes and RAM for data storage, and the ability to dynamically add new attributes to data records. At the trial locations, which are rather different in terms of population, sun, and available equipments, CoSSMic will investigate how to motivate people to participate in acquiring (more) renewable energy and the sharing of renewable energy in the neighborhood, and test methods for making money with these schemes. The Second University of Naples will develop the agents based software platform. The University of Oslo will define some behavior patterns of micro-intelligent networks, governed by selfish agents that seek to maximize the satisfaction of its users, participating in a market by mechanisms that will improve the overall performance of the electricity grid.

4 REQUIREMENTS ANALYSIS AND DESIGN

The basic functionality of the smart grid focuses on the integration of GENCO and Distributed Energy Resources (DER) in the current system, where DER refers to generators, accumulators and controllable loads connected to the electrical distribution system.

4.1 High Level Requirements

The CoSSMic Framework is composed of devices, ICT platforms and power Grid. COSSMic Framework will support sharing of information, scheduling of exchanges between power producers, consumers and energy storages in accordance with policies defined by owners, collection of data from weather stations, weather forecasts, and habits and plans of participants. At this level stakeholders include CoSSMic Users, Devices, power grid operators (GenCO). The COSSMic User will participate in two different scenarios, interacting by a GUI according to three high level use cases (UCs). The *Management* UC allows to configure and manage the available devices and to manage and control at a higher level through rules and policies the energy flows. *Monitoring* provides facilities to supervise and to potentially reconfigure the devices and the energy flows. *Reporting and statistics* integrate information from several sources, including power companies, weather reporting and forecasting and to encourage the growth of the neighborhood network. They facilitate the interaction with more and other sources of information in the future. The COSSMic Devices will use the Platform providing metering and management services. COSSMic will exchange power with GenCO when the MicroGrid cannot satisfy its requirements in the case of over- or under-production of energy within the CoSSMic neighborhoods. In Figure 2 a component diagram of the CoSSMic framework is shown. The CoSSMic platform will run on embedded computer systems which will be provided to final users as a black box, to be plugged into the power network and connected to Internet. The Platform will be installed in every household and will join a community of other instances within the neighborhood. Instances of the platform communicate by a P2P overlay and with the Cloud to eventually exploit advanced services. User's information will be bounded to the private network of each household and will be forwarded outside only with the user's agreement and for debugging purpose. Each platform instance will communicate with other households only for the energy negotiation.

4.2 The CoSSMicICT Platform

As it is shown in Figure 3 COSSMic Platform is composed of :

- a Graphical User Interface (GUI) that allows users to interact with electronic devices through graphical icons and visual indicators;
- a Knowledge Base (KB) that is an information repository that provides a means for information to be collected, organized, shared, searched and utilized;
- a Multi Agent System (MAS) to allow for the deployment of agents of consumers and producers

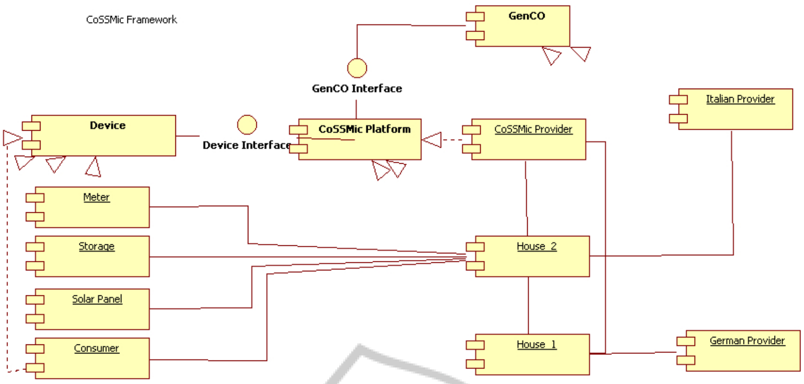

Figure 2: The CoSSMic Framework.

that will participate in the energy distribution;

- a Market for the energy negotiation within the neighborhood, and eventually with GenCO.

In particular agents will be the main actors of the CoSSMic framework. They need to connect and disconnect to the ICT network as they control the connection and disconnection of devices with the grid. Moreover they will sell or buy energy as they are capable of behave as power producer or consumer according to the device they manage. In substance, agents will be can be classified according to three categories:

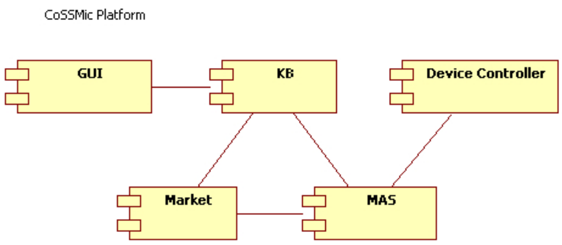

Figure 3: The CoSSMic ICT Platform.

- Consumers: they buy energy for passive devices. E.g. they will run in houses to manage objects that absorb energy: electric car, computers, ovens, washing machines, etc.
- Producers: they can sell energy. In this category there are, for example, power generators, solar panels, wind turbines.

Those devices, which are able both to produce and consume energy will be defined Prosumers. In this category there will be also storages, which are represented by a couple of agents belonging to the two different classes. In Figure 4 the MAS Use Case is depicted. Agents implement use cases to manage devices. At the same time they get information from the KB for performing the required reasoning to set

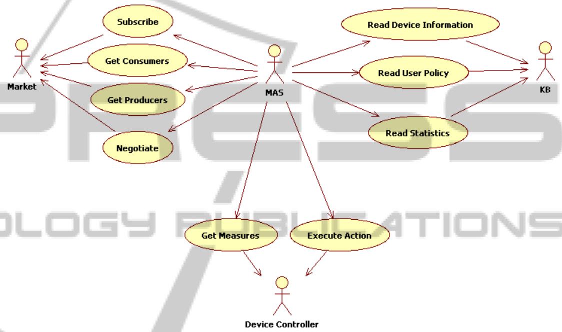

Figure 4: The MAS Use Case.

up the best negotiation strategy. An important characteristic of the agents would be the ability to handle generators and active loads in the grid using protocols and information flows, coordinating to perform certain functions in real time as, for example, to manage a peak,for dynamic load balancing, to meet a sudden drop in voltage by using energy from districts in which there is a surplus. Programming models that allow to implement selfish strategies for achieving the user's goals should be enabled. The allocation problem of mapping the consumption demand to the producible or produced energy, can be modeled as a negotiation of micro power grids agents in a marketplace over a network overlay, where an energy broker, is responsible to handle local energy flow and to exchange energy with big companies. Market use case enable agents to communicate with other agents from different households. Communication and coordination mechanisms are necessary to implement negotiation protocols and strategies which lead the system to an equilibrium that is the best compromise between the global optimum and the user's interest. The Market will be implemented over a P2P overlay. Agent and P2P concepts are closely related to selfishness, distributed system programming and P2P systems. Agents are able to improve functionality of a P2P system and also P2P architecture can be an envi-

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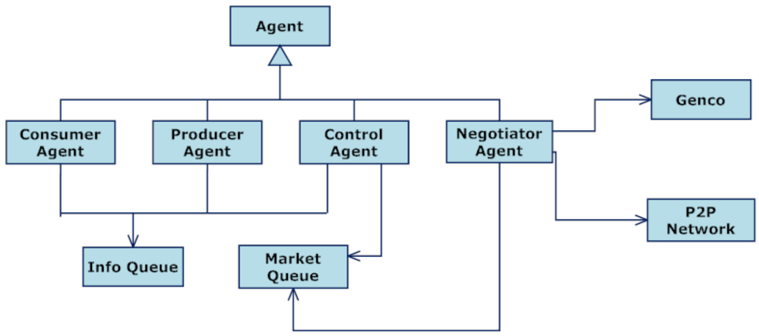

Figure 5: Structure.

ronment in which abilities of agents are fully utilized. Negotiation and brokering models among agents have been widely investigated in literature in many field and the complexity of an automated negotiation depends on several factors: the number of negotiated issues, dependencies between these issues, number of agents, representation of the utility, negotiation protocol, constraints, etc. Services are necessary to exchange any kind of information among heterogeneous entities, such as agents, smart meters, user interfaces and web services providers and requestors.

5 IMPLEMENTATION

In Figure 5 a conceptual model of the current prototype is shown. Consumer and Producer agents represent smart meters which notify their measures by an Info Queue. Control agents of each category of device subscribe to the Info Queue to be notified about changes in the household, on whose occurrence they react and plan the optimal schedule inside the household. The residual energy to be sold or to be bought are notified to the Market Queue. The Agent Negotiator is updated about the quota to be negotiated with the neighborhood or with the Genco, according to the contingency level and availability on the P2P overlay. We can observe that the message exchange in the ICT platform can occur along the same patterns used by the energy flow in the power grid.

In Micro-grids the energy is exchanged within household. The passive elements receive energy from solar panels. Also electric cars, or smart-phones and laptops are charged in the household, even if they are mobile and they consume outside(Stein et al., 2012). For this reason the smart-meters of all these devices deliver their messages to the Info Queue, directly or using Cloud services. The peer to peer network is used both if the energy produced by solar panels is not sufficient, to allows the user for contacting neighbors to have more energy, and if the produced energy is greater than the required amount. In this case the information retrieved in the Market Queue is used to look for vendors or customers by the P2P overlay. An offer is published in the P2P overlay if the required resources are currently unavailable in the neighborhood. Gencos: in case of unavailable energy offer or requirement in the neighborhood the Gencos are contacted. At the beginning of the project and in order to set-up and test the technologies we are evaluating for building the ICT platform, we have implemented a preliminary software demonstrator. For communication between agents and devices, we used a queues system in order to make their interaction asynchronous. As shown in Figure 6, two queues have been configured. Each device of the system (consumer and producer) is associated with a different agent. Consumer and producer agents communicate the amount of energy required/produced by the first queue (Info Queue). Control agents use the Market queue to agree about the internal energy schedule. The residual energy to be bought or to be sold in the neighborhood is finally scheduled and notified to the negotiator by the same queue. It look for offers in the P2P overlay and publish its offer to be contacted in turn. Labels are used to route class of messages to agents. The sequence diagram in Figure 7 shows a particular scenario where there are one consumer and one producer device. Messages with related amount of consumed/produced energy are posted in the info queue. Agents read data and report the results in a market queue. Assuming the amount of energy to be consumed is greater than that produced, the negotiator does not find any customers in the P2P and publishes

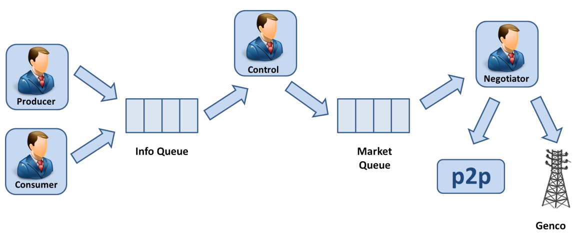

Figure 6: Prototype's Structure.

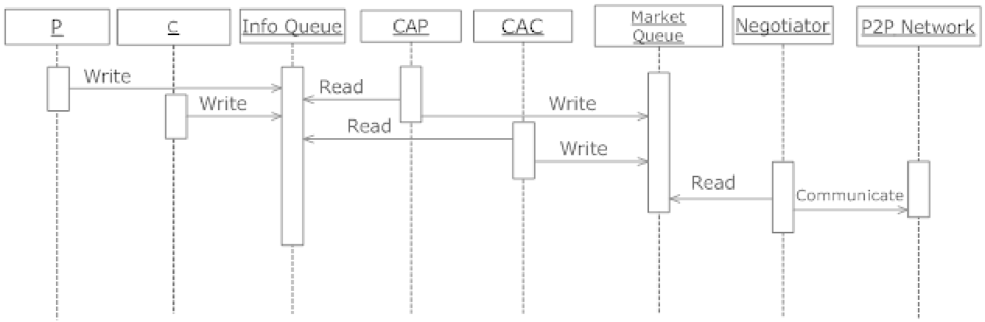

Figure 7: Sequence diagram.

its own offer.

5.1 Technological Choices

For the development of a prototype, the Jade agent platform has been used (Bellifemine et al., 2008) to develop and deploy agents. Jade is a software framework that implements an efficient agent platform in compliance with the FIPA(FIPA, 2002) specifications. As message queue Apache ActiveMQ(Snyder et al., 2011) has been chosen. It is a popular and powerful open source messaging and integration patterns. With ActiveMQ it is possible to use pure queues or topics. The substantial difference between queues and topics is that for the latter only who is subscribed to that particular topic receives the messages. Every smart home appliance is built by an embedded device Raspberry Pi running both JADE and ActiveMQ. Moreover it hosts a web based user interface. Raspberry Pi is a single board RISC (Reduced Instruction Set Computer) computer that allows to install operative system based on Linux kernel. All energy requests (both consumption and production) go through active queues on the appliance where all agents are running locally. Each producer and consumer element of the house is associated with an agent that has the main task of optimizing its use of energy and to avoid any wastage; another agent's task is ensuring that the consumer has always electricity. For simulating a consumer we developed some tests using a mobile device with Android operative system. The Android software app extends the MQTT Client that is developed by Jason Sherman and based on the FuseSource MQTT client library. This application uses MQTT protocol that is a machine to machine connectivity protocol. Through the latter it is possible to connect to a server where there is ActiveMQ and send/receive messages. In particular, as shown in figure 8, providing address, username and password to this app, it is possible to connect to the Info Queue. For experimental purpose the battery level, position, local time are

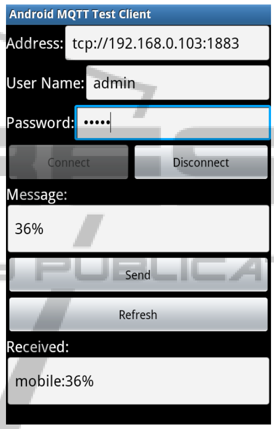

Figure 8: App Screenshot.

read and sent interactively, but also asynchronously on the occurrence of some events such as the battery full, battery low, adapter connection or disconnection. An agent receives all the messages and stores them in a MySql database, by which we can draw graphics dynamically. We made this to simulate the metering and monitoring of smart power grids.

6 CONCLUSIONS

The paper presents software architecture for supporting agents to collect information about local energy production and storage resources of neighborhoods of individual houses and to schedule the energy flows using negotiation protocols. Besides the implementation of a preliminary prototype is described. Future works will aim at replacing smartphone with smart-meters and smart-plugs in a household interconnected which will part of a sensor network that receive commands and route information to an embedding computing device hosting the described MAS. Performance bottlenecks will be identified and off the shelf software will be replaced by custom implemen-

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tations. Negotiation strategies and protocols will be implemented. We also plan to use a NoSQL database for metering and monitoring all smart power grids participating in the trials of the project.

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